

Tay R (2002). Tin Cans or Assault Vehicles? The Role of Crashworthiness and Non-aggressiveness in Vehicle Safety Design, Promotion and Regulation, *IATTS Research*, 26(2), 92-98.

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## **Tin Cans or Assault Vehicles? The Role of Crashworthiness and Non-aggressiveness in Vehicle Safety Design, Promotion and Regulation**

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### *Abstract*

This paper examines the policy implications of the traditional approach to vehicle safety, which tends to focus on the crashworthiness of a vehicle and its occupant protection capability, and an alternative approach that focus more the non-aggressiveness of the vehicle. We argue that this alternative approach will improve road safety as well as social equity and environmental quality.

Keywords: Road Safety, Vehicle Safety, Crashworthiness, Non-aggressiveness, Prisoners' Dilemma.

### **Introduction**

Road crashes are one of the leading causes of death and the leading cause of death for young people in most developed countries.<sup>1,2,3</sup> In the analysis of crash causes, contributing factors are generally classified into three categories: vehicle safety, road environment and driver behaviour.<sup>4,5</sup> The conventional approach to vehicle safety design, promotion and regulation tends to focus on the crashworthiness of the vehicle and its occupant protection.<sup>5,6</sup> Since the occupant protection capability of a vehicle is highly correlated with vehicle size, this focus has led to the common belief that bigger vehicles are safer. A sample of recent headings of articles in one major Australian newspaper includes "When big is safer",<sup>7</sup> "Play it safe - drive a 4WD",<sup>8</sup> "Small car crash tests take a battering from watchdog"<sup>9</sup> and "Parents urged to steer teens clear of tiny cars".<sup>10</sup> Another sample of headings from America reads "Bigger and heavier vehicles are better",<sup>11</sup> "Vehicles size and weights are the most important characteristics that influence crashworthiness" and "Mismatch in a crash: heavier is safer".<sup>12</sup>

This misconception about the safety effects of vehicle size on road safety has developed largely due to the traditional emphasis on occupant protection when evaluating vehicle safety. Many developed countries have invested significant amounts of resources to establish vehicle crash test programs that assess the crashworthiness of new cars and the impact on occupants in a crash. The results of these crash tests are often used by transport authorities in the development of vehicle standards, vehicle

dealers in the promotion of vehicle sales, manufacturers in the design of vehicles, media in their review of vehicles and the consumers to guide their purchase of vehicles.

The only problem with the current crash test is reality. Vehicles in real life do not crash into walls but into pedestrians, cyclists, motorcyclists, and occupants in other cars. Although crash engineers are very proficient in crashing a test vehicle into a wall and measuring the impact on occupants using crash dummies, they have yet to study the impact of these crashes on other road users outside the test vehicles. The amount of damage a vehicle inflicts on other road users is likely to be highly correlated with its size. Without reliable information on the adverse impact these crashes have on people outside the subject or test vehicle, decision are being made, and resources allocated, based only on half and arguably the less important half of the equation.

This paper aims to debunk the myth that larger vehicle are safer, which implies a trade-off between social equity, fuel efficiency and environmental concerns on the one hand and road safety on the other. When viewed from a perspective of overall safety and not just safety to its occupant, small cars are in fact safer than large cars. Therefore, downsizing the vehicle fleet not only has positive benefits for the environment but may also improve the overall safety, resulting in a lower level of trauma on the roads.

### **Is Compatibility the Right Question? Are Bigger Vehicles the Right Answer?**

As discussed earlier, the traditional approach to vehicle design, promotion and regulation tends to focus relatively more on the crashworthiness of the vehicle and its occupant protection and less on the non-aggressiveness of the vehicle (damage to non-occupants such as pedestrians, cyclists, motorcyclists and occupants of other vehicles). This misplaced focus on occupant protection has in part contributed to the misconception that larger vehicles are, on average, safer than smaller ones. This position has received widespread support in the road safety arena because it is based not only on physical laws, mechanical models and crash tests but more importantly, it is well supported by actual crash statistics.<sup>6,14,15,16,17,18</sup>

The examination of compatibility of vehicles using crash data from Japan produced some very interesting results that merited a different interpretation to highlight the problem of a misplaced emphasis in vehicle safety.<sup>15</sup> In order to illustrate the new perspective, we need to ask ourselves two important questions: (a) Is incompatibility the right question? (b) Are bigger cars the right answer? Although incompatibility is an important factor in determining the fatality risks in a two-car collision, it is nevertheless just a factor. The primary statistic of concern is still fatality risks and these indices should be the primary concern when analysing crash data. Furthermore, it could be argued that road

safety researchers and policy makers should be more concerned about the overall or total fatality risk associated with a vehicle class rather than focusing on either incompatibility or occupant protection.

Figure 1 shows the fatality risks for drivers in both the subject and other cars in Japan for several classes of vehicles. It is clear from the figure that, on average, bigger cars protect their drivers much better than smaller ones and the emphasis on occupant protection has lead many researchers to conclude that bigger cars are safer. However, if the emphasis is overall or total fatality associated with a vehicle class or type, an entirely different conclusion will be drawn. Smaller cars actually outperformed their larger counterparts because of their significantly lower aggressiveness. Therefore, in terms of determining total fatality, the non-aggressiveness of a vehicle is much more important than its occupant protection capability.

[insert figure 1 about here]

It should be noted that while the fatality rates for several other classes of vehicles were available, only the three most common types of vehicles by registration are shown in figure 1. Two other classes of vehicles that are not shown in figure 1, however, merit some discussion. On one extreme, are mini cars (Daihatsu Mira, Suzuki Alto, etc), which are quite popular in Japan but not in most western countries, have a driver fatality rates of 0.45 for subject cars (highest among all classes) and 0.05 for other cars (lowest among all classes), giving a total of 0.50. On the other extreme are the Sports Utility Vehicles (SVU) such as the Toyota Land Cruiser and the Mitsubishi Pajero, which are also commonly known as Four Wheel Drive (4WD) vehicles in some countries. Although these vehicles are not popular in Japan, they are very popular in some western countries like the United States and Australia.<sup>19,20</sup> Despite having a subject or own fatality risk of close to zero (lowest among all classes), the extremely large fatality risk of 0.73 for drivers in other cars (highest among all categories) overwhelm even the total fatality risks in all other classes of vehicles.

Therefore, in both the popular and the extreme ends of the vehicle size categories, the non-aggressiveness of a vehicle appears to be more important than its crashworthiness in determining the overall road fatality. One shocking statistic that should be highlighted to consumers and drivers is "If we are involved in a crash with a mini car while driving a SUV, the odds of the other driver suffering a fatal injury is 42 times higher than if we are driving another mini car". This statistic is true regardless of the reason(s) that contributed to the crash. This odds-ratio is much larger than most of the other deadly health and safety sins including smoking, drink driving or drunk driving and speeding.

## **Occupant Protection and the Prisoners' Dilemma**

As discussed in the introduction, the focus in the media, government websites and consumer magazines is on the occupant protection capability of vehicles, with little or no information provided on their non-aggressiveness. Therefore, it is reasonable to assume that when a consumer is choosing a vehicle, occupant protection is the dominant safety characteristics of choice. Furthermore, any injury and harm to other road users are covered by insurance. In the State of Queensland, for example, the Compulsory Third Party (CTP) insurance is collected as part of the vehicle registration fee and is the same for all passenger vehicles including small cars and large four-wheel drive. This situation creates an interesting challenge that can be analysed using the classic prisoners' dilemma framework in game theory using some data from Japan. Since the results obtained by using any two types of vehicles are the same, we should illustrate the prisoners' dilemma game using the choice between a small and a large car.

Table 1 shows the fatality risks in a two-car frontal collision for the small and large cars and table 2 shows the corresponding risks in a two-car side collision. Since our results produced by using the two types of collision are the same, we will illustrate using only the data from table 1. In a collision between a small car and a large car, the fatality risk for the driver in the small car is 0.38 whereas the corresponding risk for the driver in the large car is only 0.04. The conventional approach to vehicle safety, which focuses on vehicle incompatibility and occupant protection, would encourage the consumption of large cars based on these results. However, there are two other sets of results that also need to be considered. In a collision between two small cars, the fatality risks for both drivers are 0.20, whereas the relative fatality risks increase to 0.26 if both vehicles are large cars. These latter results are, in our alternate perspective, the more important ones in determining the overall road safety.

[insert tables 1 & 2 about here]

Consider a consumer who faces a choice of purchasing (or driving) either a small car or a large car. In the tradition of classical economic theory, we will assume that the consumer is concerned with only his/her own selfish desire to protect himself/herself. Given the information in table 1, the consumer will always choose to drive a large car because it is the dominant strategy. If the consumer driving a small is involved in a crash with another small car, his/her fatality risk is 0.20, whereas if he is driving a large car, his/her odds will be reduced to 0.04. Thus, the consumer is better off driving a large car if he/she is involved in a crash with a small car. Similarly, if the consumer is involved in a crash with a large car while driving a small car, his/her fatality risk is 0.38 whereas his/her fatality risk is only 0.26 if he/she is driving another large car. Again, the consumer is better off driving a large car. Therefore,

regardless of what the other person is driving, the consumer is always better off driving a large car, making it the dominant strategy.

Since the game is symmetric, the other consumer will also choose to drive a large car because it is also his/her dominant strategy. Therefore, in equilibrium, all other factors being constant, both consumers will drive a large car. This strategy will result in the outcome given in the lower right hand box (0.26, 0.26), which is clearly inferior to the outcome given in the upper left hand box (0.20, 0.20) - the classic prisoners' dilemma. In trying to selfishly protect themselves, the consumers have inadvertently chosen an outcome that may cause more harm to themselves and to others as well. Similarly, in trying to promote the virtues of occupant protection to consumers and to regulate vehicle safety using the crashworthiness of a car, policy makers may have also contributed to an increase in road trauma and an inefficient allocation of resources.

### **Non-Aggressiveness and Escape from the Prison**

To correct this problem, policy makers should instead promote the virtues of having a non-aggressive vehicle, to the extent of *making it dominant over the demand for occupant protection*. For example, the results of vehicle crash tests should place more emphasis on the "likelihood of killing or seriously injuring some one" and less emphasis on the "likelihood of being killed" in a crash while driving a particular vehicle. Also, vehicle design standards should place *greater* emphasis on making the vehicle less aggressive to non-occupants. If the re-education campaign is successful then the consumers' choice will be guided *more* by the non-aggressiveness of the vehicle and *less* by its occupant protection.

Again, returning to the prisoners' dilemma game, the consumer for whom non-aggressiveness is a major factor determining vehicle choice will always prefer to buy a small car to a 4WD because it is the dominant strategy. If a consumer is involved in a crash with a small car while driving a large car, his/her odds of contributing to the fatality risk of the other driver is 0.38. The corresponding risk, however, is reduced to 0.20 if he/she is driving another small car. Thus, if he/she selects the vehicle on the basis of its non-aggressiveness, then he/she would be better off driving a small car. Similarly, if the consumer is involved in a crash with a large car while driving another large car, his/her odds of contributing to the fatality risk of the other driver is 0.26, but the corresponding risk is reduced to 0.04 if he/she is driving a small car. Therefore, regardless of what vehicle the other person is driving, the consumer is always better off driving a small car, making it the dominant choice.

Since the game is symmetric, the other consumer will also choose to drive a small car because it is also his/her dominant strategy. Therefore, in equilibrium, all other factors being constant, both

consumers will drive a small car. This strategy will result in the outcome given in the upper left-hand box (0.20, 0.20) which is clearly superior to the lower right-hand box (0.26, 0.26) - escape from the prison! Therefore, it is crucial that policy makers should promote the virtue of and develop regulatory standards to improve non-aggressiveness in vehicles. This new approach will arguably increase road safety for all road users including pedestrians, cyclists, motorcyclists and drivers in both the subject car and the other car.

### **Expected Driver Fatality Risks - Single Car Collision**

Figure 2 shows the relationship between vehicle mass and driver fatality in a single vehicle collision with fixed objects such as light pole, road sign, median strip, guardrail, house, wall and bridge structures. Since vehicle size and mass are likely to be very highly correlated, we will continue the above discussion using the relationship shown in figure 2. Once again, in term of total fatality (special case where total = subject since there is no other car), the risk is, on average, an increasing function of mass. The "trend line" is upward sloping indicating a positive correlation between driver fatality and vehicle mass.

[insert figure 2 about here]

The biggest surprise is the result that smaller cars are, on average, safer than larger vehicles even in a single car collision. Since there is no contribution toward the death of drivers in the other car, this result is the fatality risk associated strictly with the occupant of the car. Laboratory crash test results, however, suggest that the occupant protection of a vehicle is positively correlated with its size. If we examine instead the second graph in figure 2 that depicts the fatality risks in crashes at low speed (below 50 km/hr), the negative relationship is much closer to what would be expected from the results of crash tests performed in the laboratories. These results suggest that laboratory tests may be a good indicator of occupant protection for low speed crashes but not for high speed crashes.

One alarming result from figure 2 is that heavier vehicles are, on average or in total, more likely to crash at higher velocity. This result may indicate that drivers of heavier vehicles may have overcompensated for their perceived lower risk due to the better occupant protection capability of their vehicles by increasing their speed. This behavioural adaptation is consistent with the risk compensation hypothesis in economics and the risk homeostasis theory in psychology.<sup>1,21,22,23,24</sup> Part of this negative behavioural adaptation can be attributed to the traditional focus on occupant protection and the myth that larger vehicles are safer. In the alternative approach where non-aggressiveness is emphasised, drivers of larger vehicles should instead compensate for the greater aggressiveness in their vehicles by reducing their speed.

### **Risky Drivers and Safer Cars**

The tendency of younger drivers to be more likely than older drivers to drive smaller cars has been an important consideration in a number of prior investigations of the relationship between car size and traffic safety.<sup>17,18</sup> Since youthful drivers are relatively more likely to be involved in a crash, part of the crash risks associated with smaller cars can be attributed to driver risks.<sup>17,18</sup> This argument, however, serves to strengthen our conclusion. If all drivers are to drive small cars, the average crash risk of small cars is expected to fall because a relatively smaller share of the driver will be considered as risky drivers. This change in the average risk is a result of the shift in the relatively safer drivers from the large car fleet to the small car fleet. Conversely, if all drivers are to drive large cars, the average crash risk associated with large cars is expected to increase due to the shift in the relatively more risky drivers from the small car fleet to the large car fleet.

Encouraging the consumption of smaller and less aggressive cars, therefore, is likely to produce safety benefits that are larger than what the current crash data would suggest. On the other hand, encouraging the consumption of larger and more aggressive vehicles would produce greater trauma than the current crash risks would suggest. Therefore, the reduction in the overall road trauma that can be expected from a shift in the mix in vehicle size of the entire fleet is likely to be greater than that outlined in the analyses above.

Another important driver influence on the relative crash risks associated with different vehicle sizes is behavioural adaptation or risk compensation discussed earlier. Examination of crash data from the United States found that the crash involvement rates were lower for small cars than they were for larger cars driven by drivers of similar age.<sup>18</sup> This result was interpreted as the consequence of driver behavioural change related to how they perceived protection to vary with car size.<sup>18</sup> In short, the perceived increase in occupant protection capability of larger vehicles induces some of their drivers to take risks and thus result in higher rates of involvement in crashes.

In a separate analysis using Japanese data, it was also found that the fatality rates of small cars were lower than larger cars.<sup>25</sup> This difference was again attributed to the greater caution drivers of small cars exhibited since small car drivers caused a significantly lower percentage of the accidents they were involved in than drivers of larger cars.<sup>25</sup> This result reinforces our earlier observation that larger vehicles tend to crash at higher speed than smaller vehicles. Both these results support the risk compensation hypothesis that the perceived better occupant capability of larger vehicles will induce some of their drivers to take more risks. Therefore, encouraging the consumption of small cars is likely to reduce the risking behaviour of drivers, resulting in a lower frequency and severity of crashes.

## **Discussion and Policy Implications**

There is a common belief both inside and outside the road safety arena that bigger vehicles are safer. This belief has largely developed due to the traditional focus on the occupant protection capability of the vehicle, which is highly correlated with its size and cost. Occupant protection is only half of the equation and, as demonstrated in our study, the less important half of the equation. For road safety researchers and policy makers, occupant protection should not be the main focus on vehicle safety. Our main concern should be on the overall road toll and social costs associated with vehicle crashes. In examining the safety effects of a vehicle, we must analyze not only the mortality and morbidity risks of its occupants in the event of a crash but also the reciprocal risks to other road users as well.

When viewed from the perspective of overall road trauma, smaller cars are in fact safer than larger cars. This differing conclusion is largely a result of the much larger negative consequences bigger vehicles inflict on other road users. Therefore, to reduce the overall road trauma, a relatively greater emphasis should be placed on the non-aggressiveness of a vehicle than on its occupant protection. This alternative approach will arguably increase social equity by reducing the overall road trauma for all road users and not just for those who can better afford to purchase a larger and more expensive vehicle. In addition to the potential road safety gains, this alternative approach may also contribute to a more efficient allocation of resources and improvements in environmental quality and social equity.

There has been a constant push over the last three decades to improve the average fuel efficiency and reduce the energy consumption of the vehicle fleet in many countries. For example, the United States of America has implemented the Corporate Average Fuel Efficiency (CAFE) standards mandating a minimum level for the average fuel efficiency rating on new car production and sales. One outcome of this legislation is the downsizing of the vehicle fleet, which raises serious concerns about its alleged impact on road safety. This concern may have been misplaced due to the myth that bigger vehicles are safer. In many western countries such America and Australia, where the average fleet size is relatively large, downsizing the vehicle is likely to improve the overall road safety and benefit the environment as well.

The high positive correlation between vehicle size and occupant protection coupled with a high negative correlation between vehicle size and non-aggressiveness implies that there is an apparent trade-off between the two desirable characteristics in vehicle safety, at least with respect to vehicle size. This apparent trade-off presents a moral dilemma - given limited resources, should the government invest more in promoting and regulating occupant protection or non-aggressiveness? Focusing relatively more on the non-aggressiveness of a vehicle than its occupant protection, however, has several advantages for the government. First, it will reduce the overall road trauma by a



greater degree. Second, it will better serve its role as the independent arbitrator and police by reducing, and hopefully addressing, the damage a member of the society inflicts on other members. Finally, as discussed earlier, this new approach will also serve to improve social equity and environmental quality as well.

It should be noted that much of the discussion in this paper is based on the high correlation between vehicle size on the one hand and occupant protection versus non-aggressiveness on the other. In reality, it may be possible to separate the two attributes. While it may be relatively more difficult to reduce the aggressiveness of a large vehicle due to its mass, it is quite feasible to improve the occupant protection capabilities of small cars (less aggressive vehicles). Therefore, to minimize the overall road trauma, policy makers should promote the consumption of small cars with good occupant protection. This could be accomplished directly by changing the vehicles design standards or indirectly by changing the relative prices of these vehicles through appropriate fiscal policies, regulations or other market incentives.

Since more aggressive vehicles are likely to inflict a larger external safety cost because of the greater damage on the road infrastructure, road-side objects and other road users, they should be taxed at higher rates than less aggressive vehicles. This externality surcharge for safety could be incorporated into the road use tax or vehicle registration fee. Administratively, taxing aggressiveness is also simpler than a corresponding fiscal policy on crashworthiness. The aggressiveness of a vehicle is determined mainly by the weight and partially by the rigidity of the vehicle and is less dependent on optional safety features such as air bags that are installed in the vehicles.

Besides a regulatory approach to change the mix of vehicle sizes in the fleet, policy makers and the media should provide a more complete set of vehicle safety information (both occupant protection and non-aggressiveness ratings) to the consumers. If given the complete information, consumers can then make a more informed choice regarding which vehicle to purchase with respect to their demand for vehicle safety. Providing this information to the public will also help to justify the differences in the taxes, fees or premiums charged for different vehicles.

Finally, vehicle testing programs and crash assessments should devote more effort into examining the aggressiveness of the vehicle and not focus solely on the crashworthiness and occupant protection capabilities of the test vehicles. This change in the relative emphasis is especially important when public resources are invested in these testing programs. The prime concern of policy makers should be on the overall safety rating of the vehicle and not just its occupant protection capabilities, and as illustrated in this paper, the non-aggressiveness of a vehicle plays a relatively greater role than its occupant protection in determining the overall safety of a vehicle.

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### **Acknowledgement**

Support from the Motor Accident Insurance Commission of Queensland is gratefully acknowledged.

The author thanks Patrick McCarthy and members of CARRS-Q for their helpful comments, and Koji Mizuno for providing several of the figures and tables.

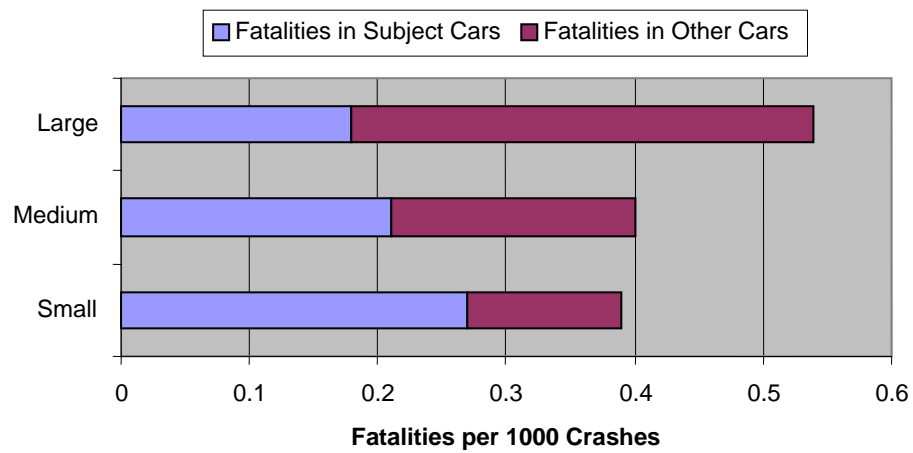
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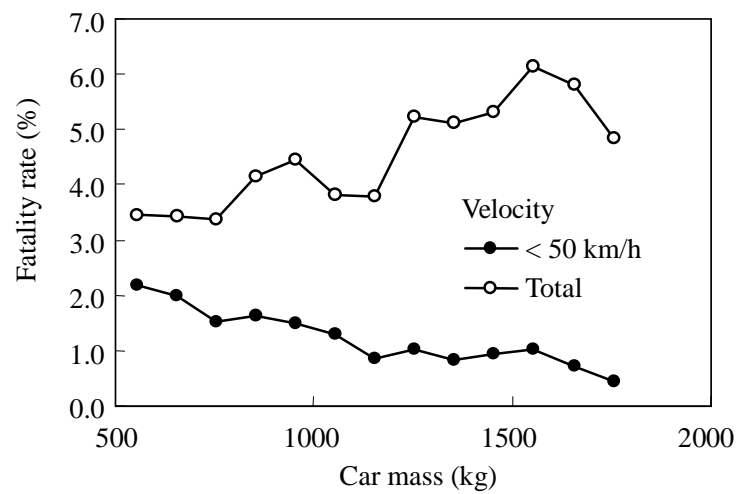
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Figure 1  
Vehicle Size and Fatalities in Japan



Source: Mizuno and Kajzer (1999)

Figure 2  
Driver Fatality Risk - Single Car Collision



Source: Mizuno and Kajzer (1999)

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Table 1  
Drivers Fatality Risks - Two Car Frontal Collision

	Small Car	Large Car
Small Car	(0.20, 0.20)	(0.38, 0.04)
Large Car	(0.04, 0.38)	(0.26, 0.26)

Source: Mizuno and Kajzer (1999).

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Table 2  
Drivers Fatality Risks - Two Car Side Collision

	Small Car	Large Car
Small Car	(0.25,0.25)	(0.55,0.15)
Large Car	(0.15, 0.55)	(0.36,0.36)

Source: Mizuno and Kajzer (1999).